Spectral and Color Characterization of a Quantum Dots Display

Khalil Huraibat[a]*, Esther Perales[a], Eric Kirchner[b], Ivo van der Lans[b], Alejandro Ferrero[c], Joaquín Campos[c], Francisco Miguel Martínez-Verdúa

[a]*Department of Optics, Pharmacology and Anatomy, University of Alicante, Alicante, SPAIN*
[b]*Color Research, AkzoNobel Performance Coatings, Sassenheim, THE NETHERLANDS*
[c]*Instituto de Óptica, Consejo Superior de Investigaciones Científicas (CSIC), Madrid, SPAIN*

**kh40@alu.ua.es*

ABSTRACT

Digital simulation by rendering gonio-apparent objects it becomes a necessity due to the huge impact is giving day by day in different industries. However, in a recent publication, the limitations of a conventional LCD display for this goal was shown, since many visual attributes of goniochromatic coatings fall outside the color-gamut of this type of electronic display. Consequently, gamut-mapping algorithms, new extended RGB color spaces and/or multi-primaries displays are necessary to reproduce faithfully the colorimetric properties of these materials. Recently, quantum dots (QD) displays appeared in the market with attractive characteristics. QD are semiconductor nanocrystals that provide lifelike colors in an energy-efficient way. Thus, a wide color gamut is achieved. Therefore, a proper color characterization and calibration of this type of displays is needed. For this study, a spectral and color characterization of a QD display is performed. For this purpose, the spectral radiance of a set of images was displayed on a QD display and measured by a tele-spectroradiometer. As results, a good chromaticity constancy of primaries was obtained after black correction is applied. It was checked that this display satisfies channel additivity and the electro-optical transfer function for the three channels can be modelled as a power function. The GOG model was found to well characterize this display. Color reproduction was evaluated in terms of CIEDE2000. The computed CIELAB values of a set of images differ from their objects' coordinates by an average value of $\Delta E00 = 1.07$. Therefore, we conclude that the accuracy obtained with the GOG model is sufficient to get good performance in 3D rendering. On another hand, the spatial uniformity of the display is checked. The display shows poor spatial uniformity in terms of luminance, while the uniformity considering chromatic values shows much better results.

KEYWORDS: display characterization, color rendering, Quantum Dots.

INTRODUCTION

Digital simulation is becoming an important tool in many areas, looking for impressive and wonderful results more life-like colors and more realistic objects simulation, which is the case in many industrial applications. With the appearance of the new goniochromatic coatings [1], these material produces attractive color effects [2, 3]. Gonio-apparent colors are characterized by having different spectral reflectances [4]. From that, digital simulation by rendering and replication of gonio-apparent coatings is requested. A good display technology device is essential to assure the reproduction reliability in terms of colors and spectral information. Previous studies evaluate the validity of the available display technologies for the visualization of goniochromatic colors. The limitations of the conventional LCD display was mentioned [5]. Considering these limitations, gamut mapping algorithms [6], new extended RGB color spaces and/or multi-primaries displays are necessary to faithfully reproduce the visual attributes of objects built with these materials.

Quantum dots display technology is recently released in the market with promising attractive characteristics such as a wider color gamut due to the spectrally pure emission. QD provides vivid colors in an energy-efficient way [7, 8]. All these makes it a promising technology to be used for visual experiments and specially for goniochromatic colors reproduction. The aim of this work is to study the validity and the performance of the QD technology for the digital color reproduction of gonio-apparent colors. First, a proper color and spectral characterization will be performed, then, the spatial uniformity of the display will be evaluated.

THEORY

The standard color display calibration method "gain-offset-gamma" (GOG) was mainly used for CRT displays, however, is also common to use in visual science and experiments. This model is applied to check its validity for the new QD display technology (a non-CRT display)[9, 10]. This method provides the existent relation between the channel signal of the display and the luminance generated by this channel (electro-optical transfer function) through the equation:

$$\frac{L}{L_{\max}} = \left(g_i \; NDR_i + o_i\right)^{\gamma_i} \qquad i = R, G, B \tag{1}$$

where gi and γi are the parameters to adjust the curve, oi the offset for each channel, where oi + gi =1 and NDRi is the value of the relative or normalized digital value ($ND/2^{bits}$ -1) of each channel: Red, green and blue, considering the depth of bits (for example, 8 bits is equivalent to 256 digital levels per channel). Therefore, conceptually, the values of L/L_{max} for each channel RGB are equivalent in our case to the colorimetric values RGB of the display. The transformation matrix (RGB ➔ XYZ) is applied. The X(R,G,B), Y(R,G,B) y Z(R,G,B) on the matrix are the tristimulus values of the primaries activated with the maximum, and the matrix RGB represents the luminance of each channel obtained considering equation (1). Two main conditions should fulfil, then we can apply the GOG model. The first is constancy of primaries, the second is the additivity and depending on the compared values, we evaluate the luminance additivity or the tristimulus additivity.

EXPERIMENTAL

For this study, the display to be characterized is the Philips Brilliance LCD monitor (MultiView 272P4QPJKES Quad HD 27" / 68.6cm 2560 x 1440) was selected. A set of images to measure several luminance values of RGB was generated by using MATLAB® (The MathWorks, Inc.) on a desktop computer, where 18 different stimuli (images) are selected to cover the 8-bit grayscale values (0 to 255) for each channel. A small interval of 5 units was chosen to cover completely the low levels [0-50], while a wider interval of 25 units is selected to cover the rest of the range [50-255], the choose of a small interval in the low levels is due to the small radiance changes which allows a better representation of this problematic area. Two more stimuli were generated to simulate the white stimulus and the dark stimulus. Luminance and spectral measurements are carried out using the tele-spectroradiometer Konica Minolta CS2000. Measurements are performed with a 2º field of view, the objective of the tele-spectroradiometer perpendicular to the display, pointing to the center and placed at about 50 cm of it. Stimuli images are displayed on full screen and dark room. The automatic display adjustment is deactivated and fixed to the maximum brightness. The measurements output file contains the luminance, the chromaticity coordinates and the spectral information (from 380 nm to 780 nm) for each stimulus.

RESULTS AND DISCUSSION

The spectral distribution is obtained for all the stimuli, for the white and for the black stimuli. The spectral radiance characteristics of the display are illustrated in figures 1 (A, on the left). It shows the spectral profile of the RGB primaries compared to the white (black curve). The spectrum has maximum emission in three regions (454 nm, 527 nm and 632 nm). The red and blue channels spectra are narrower than the green one. The maximum spectrum emission matches with the white peaks for the three channels. Figure 1 (B) shows the nonconstancy of primaries. This can be related with the non-zero luminance of the black, therefore a black correction is applied [11], which leads to the following results shown on Figure 1 (C). Therefore, we can assume primaries constancy based on this correction ignoring the small aberration for the low levels, especially for the blue and red channels.

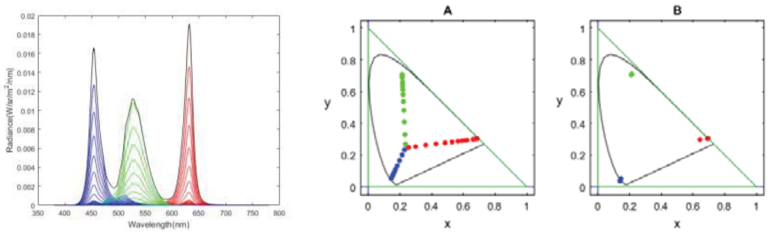

Figure 1: (A) Spectral profiles of the RGB channels for the 18 different digital count levels at each channel separately, (B) Stimuli chromaticity representation (primaries), (C) Stimuli chromaticity representation after black correction

The luminance and the tristimulus additivity were examined separately. From tables (1) it is possible to confirm the luminance additivity as well as the tristimulus additivity. Therefore, the transformation matrix mentioned before can be applied since the chromaticity constancy of primaries and additivity conditions fulfil.

Table 1. Verification of the luminance and tristimulus additivity

	Y (cd/m2)	X	Y	Z
R+G+B	378	337.44	376.42	442.94
White	376	338.82	378.18	446.36
Difference (%)	0.27	0.41	0.47	0.77

The electro-optical transfer function describes the relationship between the signal used to drive a given display channel and the luminance produced by that channel. Since the XYZ values obtained for the NDR = 0 is null, and the offset value is zero due to the black correction, then, the fitting should be done for the curve applying equation (1) but removing the offset oi component. Figures 2 illustrates the measured electro-optical transfer function (General model Power 1).

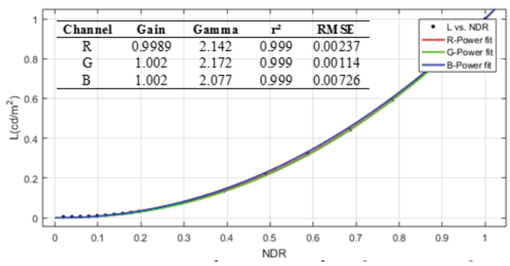

Figure 2. Power fit curves for the RGB-channel

The GOG model fulfils. The transformation matrix gives the XYZ values from the RGB values. A proper evaluation process is carried out by applying the resulting method on 16 different images generate with different combinations of digital count levels, where ΔE_{00} between the measured and computed LAB values after applying the method is computed. The resulting ΔE_{00} confirms the validity of the GOG method where the average ΔE_{00} is 1.39. Another evaluation is performed to test whether the color gamut of QD monitor verifies the ITU-R Recommendation BT.2020 color space[12]. After computing the difference between both color gamut, we obtained that the Philips Brilliance LCD Quad HD monitor color gamut covers 81% of the Rec.2020 color space.

The spatial uniformity of the display is evaluated. The display is divided in a mesh of 9 squares, the measurements are performed on the center of each square. The uniformity is studied separately in terms of luminance and chromaticity in between the 9 positions. Results shows poor uniformity in terms of luminance while the chromatic uniformity seems to be much better. The left graph on figure 3 shows the difference of luminance between the different positions where the central point has the maximum luminance value. These results are similar for other two channels. On the right graph is easy to observe the similarity between the values of the x-chromaticity coordinate between the different positions, these results are similar for the green and blue channels. The y-coordinate shows similar results.

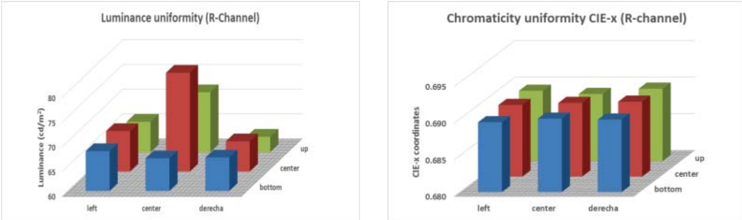

Figure 3. Uniformity representation for the 9 positions on the display. Left: shows the luminance uniformity on the R-channel. Right: shows the chromaticity uniformity for the R-channel in x-chromaticity coordinate.

CONCLUSION

As results, the GOG model is found to well characterize the QD display. It was evaluated by computing the CIELAB values for the test images and their objects' coordinates. The computed CIELAB values of a set of images differ from their objects' coordinates by an average value of $\Delta E00 = 1.39$. We conclude that the accuracy obtained with the GOG model is sufficient to get good performance in 3D color rendering. The uniformity was not the expected even it shows good chromaticity uniformity. Nevertheless, the chromatic uniformity can be enough for 3D color rendering, since the color values doesn't change a lot through the display. The QD technology also shows large color gamut covering 81% of the Rec.2020 color space.

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